Effect of Handling, Storage and Cycling on Ni-H_2 Cells: Second Plateau Phenomenon

Hari Vaidyanathan
Lockheed Martin Global Telecommunications
And
Gopalakrishna M. Rao
NASA/Goddard Space Flight Center

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Background

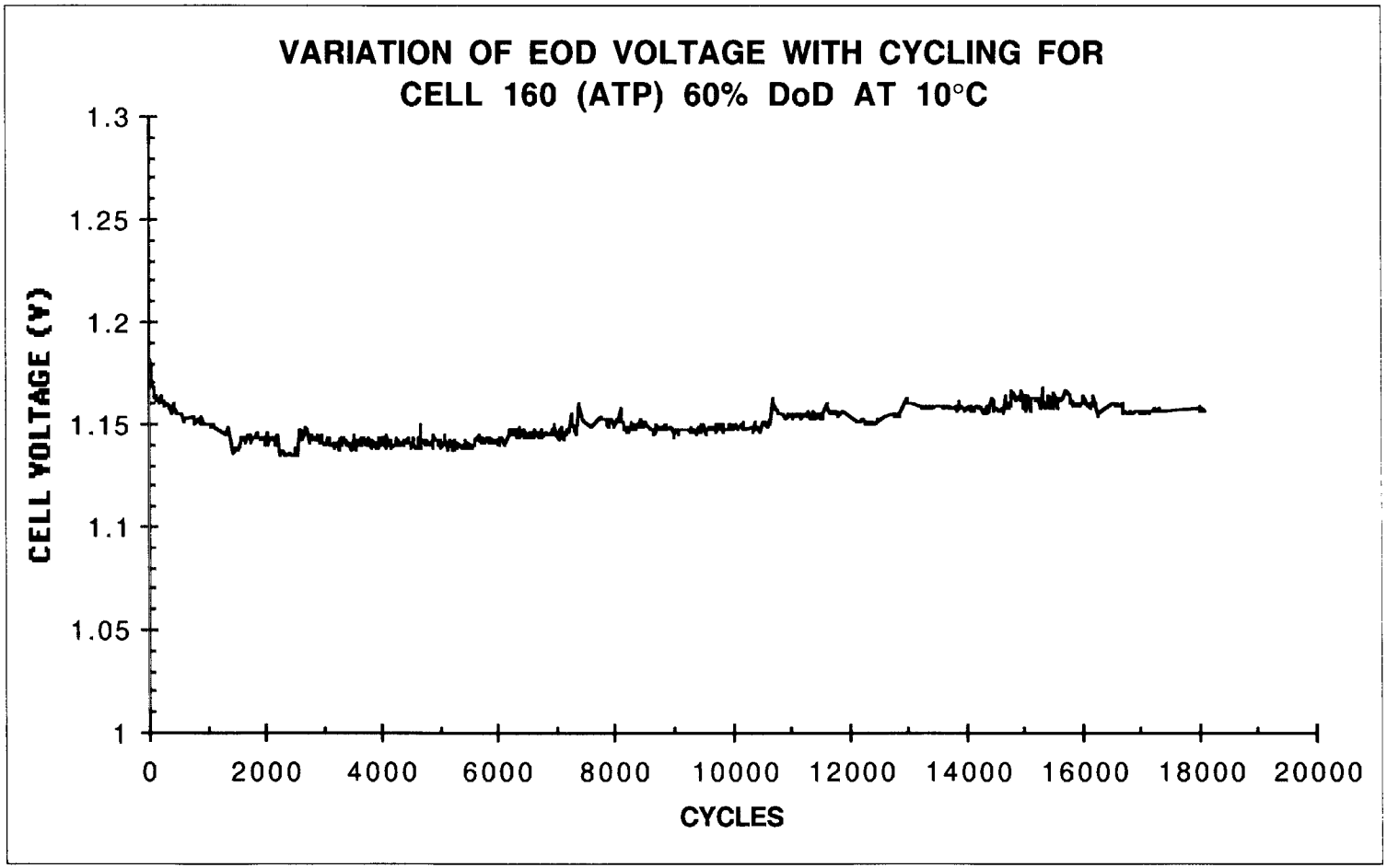
- The discharge voltage profile for some Ni-H_2 cells exhibits a second plateau at about 0.8V
- The capacity at a lower voltage plateau results in loss of useful energy
- The proportion of capacity in the second plateau varies with handling, storage, use and cycling

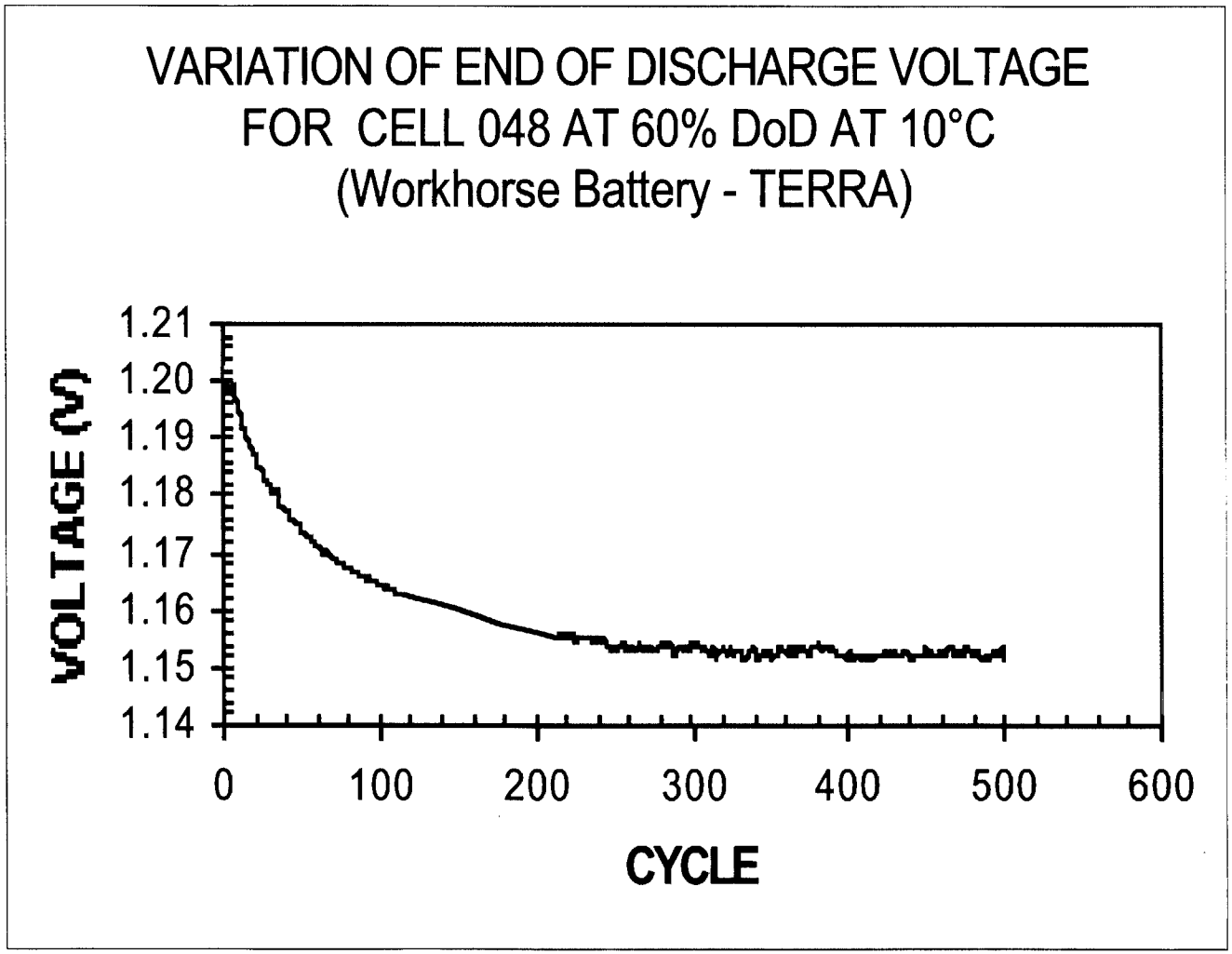
Criteria for Cell Selection

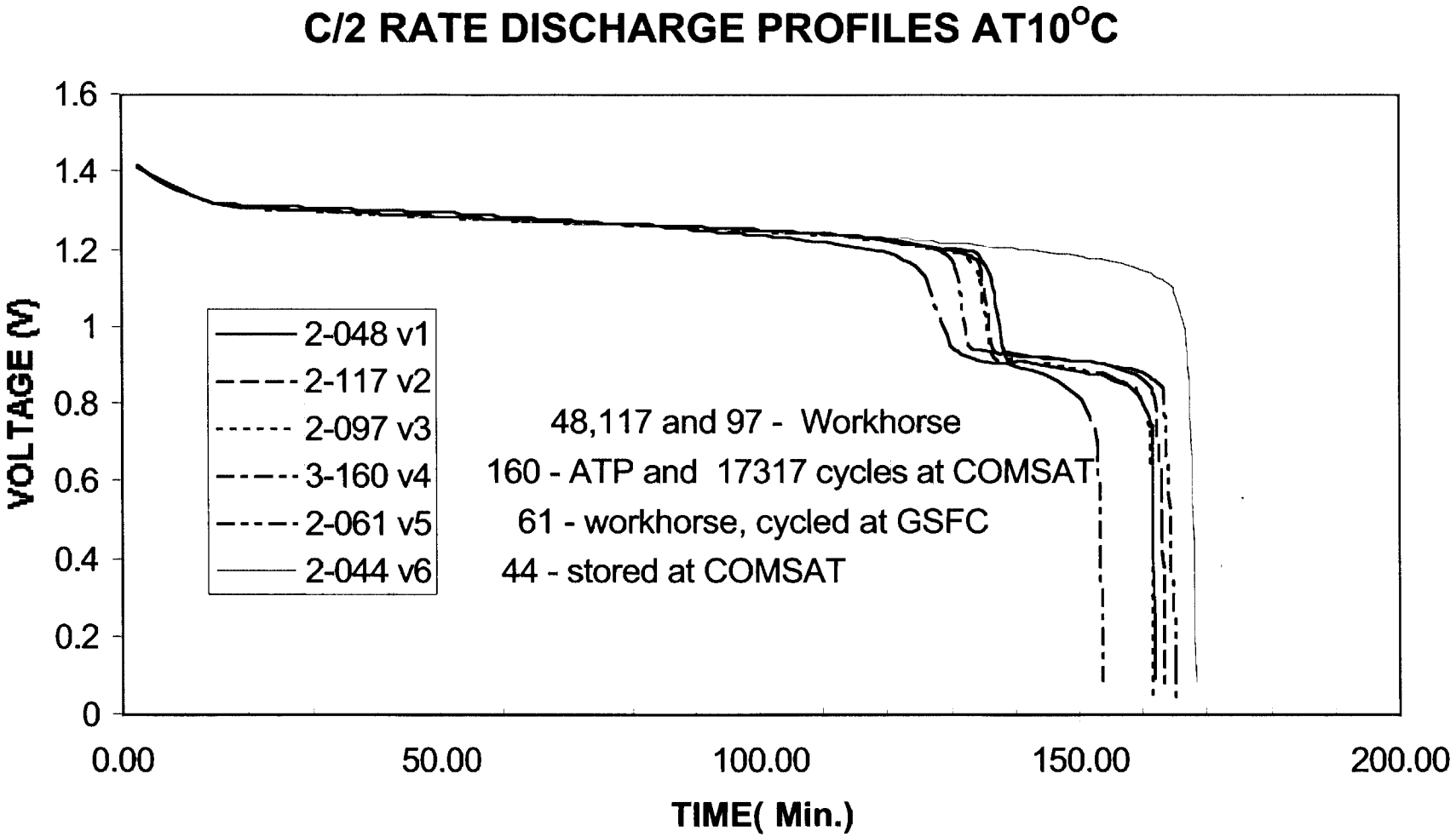
- Cells received after ATP from the Vendor
- Cells stored cold in discharged open-circuit conditions
- Cells stored dry/cold and activated in later years
  - Room temperature exposure
- Cells removed from a workhorse battery
  - Room temperature exposure
  - Intermittent charging
  - Extensive use
  - Cell reversal

Cell History

CELL I.D.	HISTORY
TERRA - 50 AH	
2-044	STORED AT LOW TEMP
1-005	STORED AT LOW TEMP
2-117	WORKHORSE BATTERY
2-146	WORKHORSE BATTERY
3-160	17317 LEO CYCLES (40% DOD AND 10°C)
3-205	STORED AT LOW TEMP
2-097	WORKHORSE BATTERY
2-048	WORKHORSE BATTERY
2-061	WORKHORSE BATTERY/500 LEO CYCLES (40% DOD AND 10°C)
HST - 93 AH	
10-515	ATP
10-511	DRY STORED (2 YRS), STORED UNCONTROLLED (1 YEAR) AFTER ATP
10-512	DRY STORED (2 YRS), STORED UNCONTROLLED (1 YEAR) AFTER ATP
11-754	DRY STORED (2 YRS), STORED UNCONTROLLED (1 YEAR) AFTER ATP
AQUA and AURA - 160 AH	
1-041	ATP
2-102	ATP, SEAL REWORK, ATP

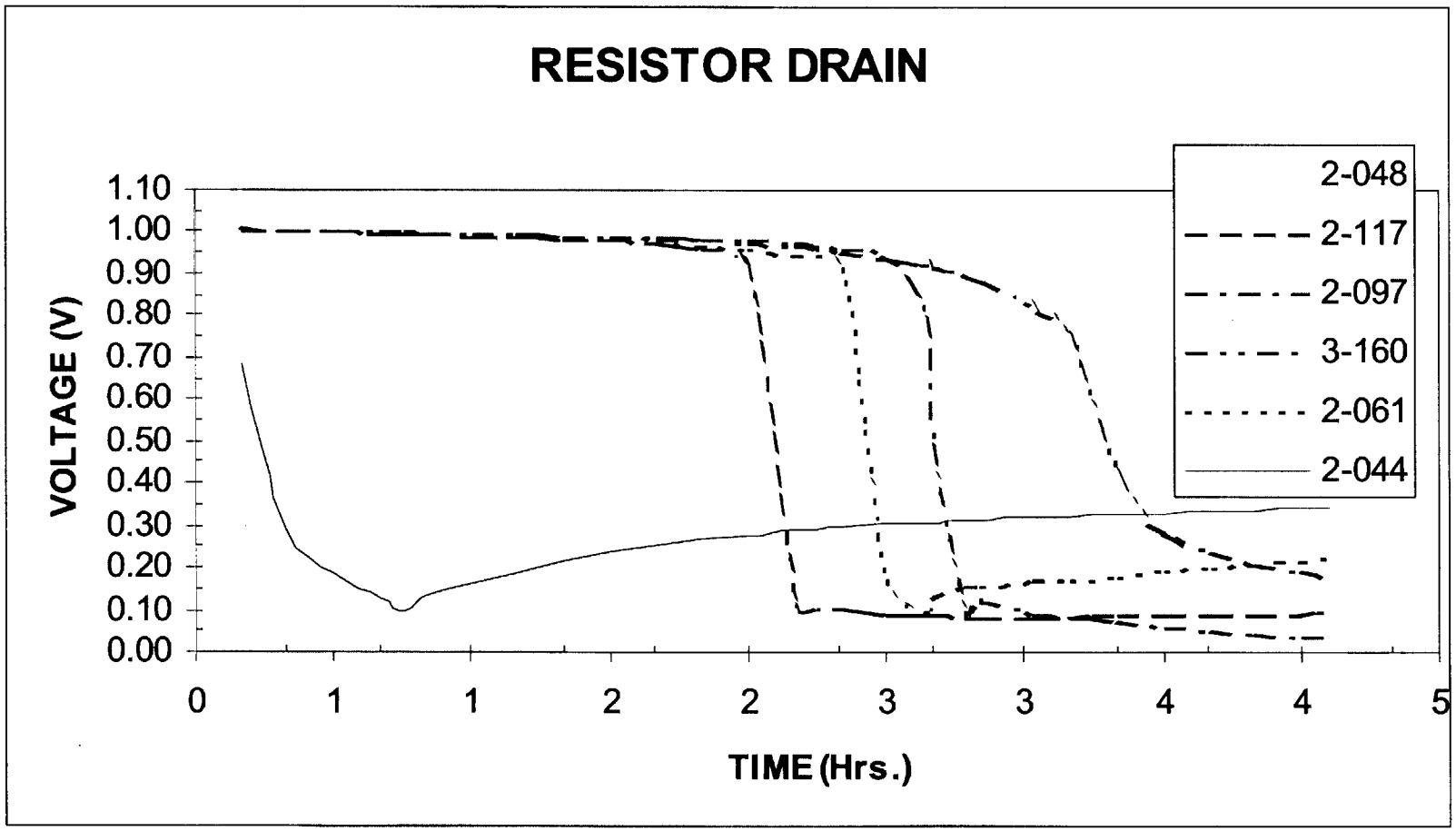

VARIATION OF EOD VOLTAGE WITH CYCLING FOR
CELL 160 (ATP) 60% DoD AT 10°C
CELL VOLTAGE (V)
1.3
1.25
1.2
1.15
1.1
1.05
1
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
CYCLES


VARIATION OF END OF DISCHARGE VOLTAGE
FOR CELL 048 AT 60% DoD AT 10°C
(Workhorse Battery - TERRA)
VOLTAGE (V)
1.21
1.20
1.19
1.18
1.17
1.16
1.15
1.14
0
100
200
300
400
500
600
CYCLE


C/2 RATE DISCHARGE PROFILES AT10°C
VOLTAGE (V)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.00
50.00
100.00
150.00
200.00
TIME(Min.)
2-048 v1
2-117 v2
2-097 v3
3-160 v4
2-061 v5
2-044 v6
48,117 and 97 - Workhorse
160 - ATP and 17317 cycles at COMSAT
61 - workhorse, cycled at GSFC
44 - stored at COMSAT

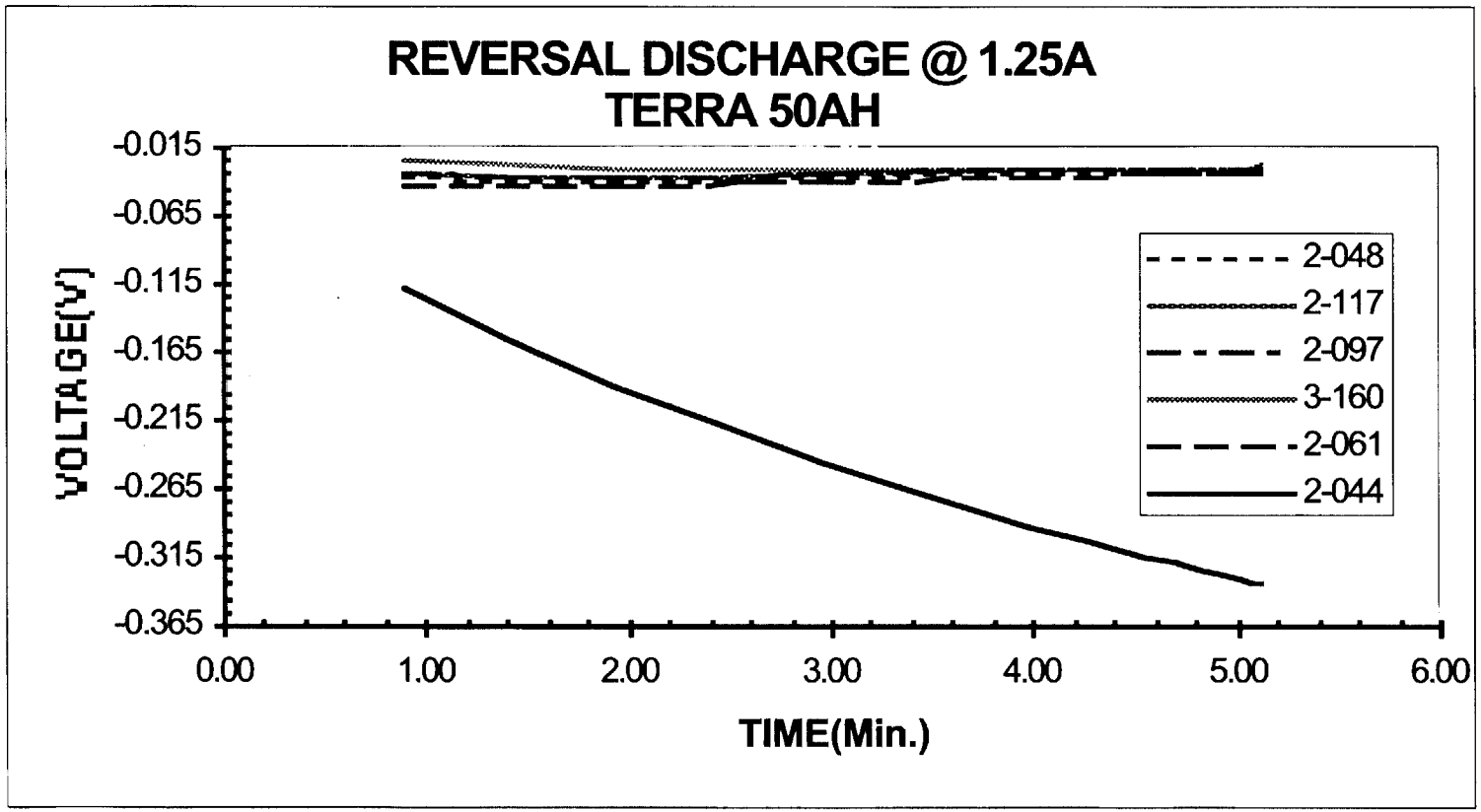
Second Plateau Capacity at C/2 Discharge

CELL I.D.	HISTORY	Capacity AH,10°C		SECOND PLATEAU
		1V	0.1V	CAPACITY, %
	50 AH, TERRA			
2-044	Stored at low temp.	68.9	69.7	1.1
1-005	Stored at low temp.	63.6	64.3	1
2-117	Workhorse battery	56	63.8	12.2
2-146	Workhorse battery	62.5	63.9	2.2
3-160	17317 LEO cycles	53.4	64.5	17.2
3-205	Stored at low temp.	63.7	64.2	0.78
2-097	Workhorse battery	55.2	67.5	18.1
2-048	Workhorse battery	56	67.7	17.3
2-061	Workhorse battery, 500 LEO cycles	54.4	68.9	21
	93 AH, HST			
10-515	ATP	84.2	88.7	5
10-511	Dry storgae, Uncontrolled storage after ATP	93.4	98.3	5
10-512	Dry storgae, Uncontrolled storage after ATP	93	99.3	5.9
11-754	Dry storgae, Uncontrolled storage after ATP	91.8	97.5	5.8
	160 AH, AQUA and AURA			
1-041	ATP	184.7	185.1	0.3
2-102	ATP, Seal rework, ATP	192.2	192.9	0.2


RESISTOR DRAIN
VOLTAGE (V)
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1
1
2
2
3
3
4
4
5
TIME (Hrs.)
2-048
2-117
2-097
3-160
2-061
2-044

Cell Reversal Test Condition

- Temperature = 20°C
- Charge at C/10 for 16 hrs followed by two discharges at C/2 to 1V and at C/20 to 0.01V and then resistive drain to 0.005V
- Reversal discharge at C/40 for 5 minutes


REVERSAL DISCHARGE @ 1.25A
TERRA 50AH
VOLTAGE[V]
-0.015
-0.065
-0.115
-0.165
-0.215
-0.265
-0.315
-0.365
0.00
1.00
2.00
3.00
4.00
5.00
6.00
TIME(Min.)
2-048
2-117
2-097
3-160
2-061
2-044

GAS ANALYSIS

CELL I.D.	GAS CONTENT
50 AH TERRA cell(2-044), stored at low temp.	No gas present
50 AH TERRA (2-061), workhorse, 500 cycles	vacuum
50 AH TERRA (2-097), workhorse	No gas present
50 AH TERRA (2-117), work horse	H2 less than 100mL
50 Ah TERRA (3-160), ATP, 17317 cycles	H2 3700 mL
50 AH TERRA (2-146), workhorse	vacuum
50 AH TERRA (3-205), stored at low temp.	vacuum
93 AH HST (11-754), stored uncontrolled 1 year	vacuum
93 AH HST (10-511), stored uncontrolled 1 year	vacuum
93 AH HST (10-512), stored uncontrolled 1 year	vacuum
93 AH HST (10-515), stored uncontrolled 1 year	vacuum
160 AH AQUA (1-041), ATP	vacuum
160 AH AURA (2-102), ATP, seal rework, ATP	vacuum

NICKEL PRECHARGE

CELL ID	CAP 20°C	PRECHARGE*, AH			
	AH	ELECTRICAL	CHEMICAL	TOTAL	TOTAL, %
50 AH TERRA (2-044)	58.9	0.3	8.0	8.3	16.5
50 AH TERRA (2-117)	49.1	0.0	14.6	14.6	29.2
50 AH TERRA (3-160)	47.5	0.0	9.1	9.1	18.1
50 AH TERRA (2-146)	58.7	0.7	1.3	4.5	8.9
50AH TERRA (3-205)	57.3	1.0	8.7	9.7	19.4
93 AH HST (10-511)	89.3	0	7.9	7.9	8.8
93 AH HST (10-515)	78.6	1.4	12.8	13.2	14.7
160 AH AQUA Cell (1-41)	150	8	19.3	27.3	17.1
160 AH AURA Cell (2-102)	165	IN Progress			

* Based on measured 20°C Capacity

Summary

- Cell stored at low temperature did not exhibit a second plateau in the discharge profile
- Second plateau occurs in cells that are subjected to excessive use, high temperature exposure, intermittent charging, cell reversal, and cycling
- Cells exhibiting second plateau also have a large residual capacity at a lower voltage of about 0.8 V and a voltage plateau at 1V during resistive drain
- Gas analysis indicated the presence of large quantity of hydrogen in the cycled cell and relatively small quantity of hydrogen in ONLY one of the cells that exhibited second plateau
- Chemical analysis indicated the presence of Ni^{+3} in discharged positive plates

Conclusions

- Proper handling of Ni-H_2 cells/batteries in storage, during I&T, and at launch site is very important to preserve the useful energy and to extend the mission life
- Cell reversal test is not a prudent test to verify or quantify the nickel precharge in Ni-H_2 cells/batteries
- The second plateau is due to the formation of Ni^{+3} that is electrochemically inactive
- Gas analysis of the cell, and Chemical analysis of the positive plate are confirmatory tests to determine the nature of precharge in Ni-H_2 cells